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Optimal crop combination under soaring oil and energy prices in the kingdom of Saudi Arabia

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ABSTRACT

There is a growing consensus that increasing costs of production, engendered by soaring oil and energy prices, have a negative effect on crop production, productivity, and efficiency. The oil and energy subsidy removal in the Kingdom of Saudi Arabia (KSA) necessitates conducting this study, which aimed to determine optimal cropping patterns under soaring oil and energy prices and to compute the comparative and competitive efficiencies of crop production. The study used combined analytical approaches, namely: linear programming (LP) and policy analysis matrix (PAM). It is perceived that crop production was highly profitable in the prevailing market and soaring oil and energy prices. However, the results of the optimal LP model reveal that returns from the cultivated crops in the study area surpassed the actual one by about four times. Furthermore, subsidy removal has reduced the total consumed amounts of energy and water constraints; however, the resources used are insufficient. On the other hand, all cultivated crops have shown high competitiveness with some crops gaining indirect export support. Thus, to achieve the maximum benefits of subsidy removal from the energy sector, the agricultural authority should adopt good extension programs to improve farmers' knowledge and skill in the field of farm management practices and efficient use of the resources.

1. Introduction

Saudi Arabia, the well-known oil kingdom, is the largest country in the Middle East, occupying an area of more than 2 million km^2 [1]. The climate of the Kingdom of Saudi Arabia (KSA) varies from one region to another due to dissimilarity in the topography. Yet the prevailing climatic pattern is the desert one, except the southwest region, which features a semi-arid climate [2]. As a result of harsh weather, agricultural activities (crop cultivation) are practiced in limited areas, namely, Riyadh, Hail, Tabuk, Buraydah, Eastern region, Al-Ahsa Oasis, Qatif, Asir, Jazan, and Medina [3]. Modern farming is the dominant system in the KSA. The focus of agricultural production in the KSA is mostly self-sufficiency, however, for its 2030 Vision, the KSA has put much attention into the agricultural sector to secure food for the increasing population and export the surplus. It is worth mentioning that the food demand in the KSA is changing, but with an increasing pattern. It increased by about 1.3% from 2017 to 2019 [4]. Despite the unsuitable climatic condition, the contribution of the agricultural sector to the KSA's GDP across 2018, was recorded as 2.2% [5]. In the same vein, the country's GDP growth rate in the same year was 2.84% [6].

In the past, the KSA has subsidized its oil, gas, and electricity for a long period to distribute its financial resources equitably [7] and achieve other economic and social objectives [8]. In 2018, the country made great economic reform by removing oil and energy subsidies to reduce oil consumption and misallocation and to control CO2 emissions. Such subsidy removal has a negative impact on the agricultural sector, as any increase in oil and energy prices might be negatively reflected in costs of all items connected to crops inputs, such as material inputs, energy inputs, and machinery inputs. Moreover, in light of oil and fuel prices, and due to fluctuations and changes in weather and resource-use inefficiencies, some negative consequences have arisen regarding crop yield and its prices. Furthermore, the instability of agricultural rotation, coupled with a sharp increase of input costs, might reduce crops outputs, thus, decreasing farms' yield and farmers' income, resulting in poor farm savings and investments; changing consumers' behavior and marketing process; and additional dependence on export markets [9]. Moreover, there is a strong relation between oil and commodities' prices [10].

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Al-Ahsa province, as one of the main agricultural areas in the KSA, and like many other regions of the KSA, has encountered many crops production challenges that have a substantial effect on crop yields. The most important of them are high input prices, deficiency of irrigation water, and small size of landholding. Furthermore, increasing resource prices motivated by oil and energy subsidy removal might have a negative effect on the productivity and effectiveness of some crops' production.

While many studies have been run to assess the optimal crop combination and economic efficiency and competitiveness of the crops in the world, research is lacking on how subsidy removal of oil and energy affects crop production in the KSA. Such findings will help policymakers and investors make the right decisions for improving the agricultural sector in the country. This study aims to identify the relationship between farmers' demographic factors and crop production; determine the optimal crop combination under the prevailing situation of soaring oil and energy prices; and examine the incentive of economic policy on economic efficiency and competitiveness, based on production aspects of the cultivated crops. However, it is noteworthy to mention that the focus of this study is the main vegetables, fodder, and cereal crops produced in the study area: tomatoes, potatoes, eggplant, ladyfinger, zucchini, barley, and alfalfa.

The idea of this study is to explore the application of combined analytical methods (LP and PAM) in constructing optimal crop combinations under the impact of subsidy removal of the energy sector.

The study is divided into four sections. The first section is devoted to the introduction and literature review related to the study. The second section displays the material and methods. The third section illustrates the results and discussion, and the last section highlights the conclusion.

1.1. Literature review

Based on the available literature, many studies have been conducted to assess the impact of mixed cropping on crop yield and productivity, optimal crop combination, economic efficiency, and crops competitiveness. Other studies were performed to examine the conflict between resource degradation and economic growth [11–13]. Thus, in this section, the studies performed for analyzing the crop combination and the factors affecting it were illustrated applying various mathematical and economic models, for instance, correlation studies on demographic factors and crop production, linear programming (LP) studies, Policy Analysis Matrix (PAM) studies, and oil and energy price studies.

1.1.1. Correlation studies on demographic factors and crop production

Several studies used Spearman and Pearson correlation analysis for investigating the relationships between demographic factors and crop production and their related issues [14]. Luck et al. [15] used the Pearson correlation analysis to study the demographic factors and vegetation change in urban ecosystems, finding that housing density had a positive relationship with vegetation cover. Similarly, Dutta et al. [16] found a positive association between farming experience and maize productivity. Likewise, Cevher et al. [17], found a positive correlation between non-agricultural income and education status in their study of alfalfa production in smallholder farms of eastern India. Likewise, Simelton et al. [18] used the Spearman correlation for studying the association between grain crops and demographic factors, finding that the technical inputs of crop production, such as fertilizers and agricultural land, are significantly correlated to demographic factors.

1.1.2. Linear programming (LP) studies

The problem of optimization is commonly solved with the help of the LP approach [19,20]. LP is usually used in the agricultural sector to determine optimal resources allocation “profit-maximizing or cost minimization” [21–23], given limited resources. For instance, the LP can be used in regions suffering from water deficits to allocate water among farmers in an efficient manner. The model can be used to solve a wide spectrum of problems. Singh et al. [24] have developed an LP model with a decomposition algorithm to determine the global optimal cropping plan of the region and to solve the water efficiency problem. Furthermore, Obi-Anike and Okafor [25] used the LP technique to help decision-makers in Nigeria improve the industry sector to reach sustainable production, proving that the LP technique is an effective tool to facilitate rational decision-making. Moreover, the LP model can also be used in the optimization of the business activities of dairy farms characterized by crop-livestock integration, Gameiro et al. [22], argued that the LP model might be used as a decision tool to optimize dairy farms' (integrated crop-livestock farm) activities, taking into account environmental aspects.

1.1.3. Policy analysis Matrix (PAM) studies

Many authors adopt the PAM approach in the analysis of competitiveness and economic efficiencies. A study performed by De Freitas et al. [26] determined that the distorting policies associated with market imperfections directly affected the corn production systems in Brazil, and the agricultural corn production systems in Brazil were net taxed while the private profits were reduced, bargaining its production and commercialization. Similarly, De Souza et al. [27], performed a study to assess the competitiveness and production efficiency of a rice chain in Brazil and Uruguay. Their results revealed that the rice chain was competitive under the existing market and policy conditions. Furthermore, Scheiterle and Birner [28], adopted the PAM approach to analyze the comparative advantage of maize production in northern Ghana and concluded that maize production systems have the potential to increase productivity and achieve food security. In the same manner, Pahlavani et al. [29] used the PAM method to analyze the dynamic comparative advantage, where they confirmed that the pastoral system has a more dynamic comparative advantage in comparison to other production systems. Another study performed in Iraq revealed that government intervention supports and improves cereal crops in the country [30].

Recently, Gonchigsumlaa et al. [31] used the PAM method to analyze the private and social competitiveness of sea buckthorn farming in Mongolia, indicating that the social competitiveness of sea buckthorn surpassed the private one. They also mentioned that most competitive sea households had larger land sizes and had more years of experience in sea buckthorn farming than others. However, few authors combined PAM with other models for estimating and evaluating the economic contribution of comparative advantages and profitability. Posadas-Domínguez et al. [32] used a combination of PAM with the poverty line approach to assess comparative advantages, private profitability, and competitiveness of small-scale dairy systems. Their results indicated that food purchase has a comparative advantage, but with high sensitivity to cost rise. Prišenk et al. [33] and Prišenk et al. [34] have also employed a combination of LP with weighted goal programming (WGP) to optimize agricultural holdings and processes on farms. They argued that from an economic viewpoint, WGP, including the LP model, provides a better solution than using the LP model alone.

1.1.4. Renewed energy studies

Renewed energies, such as wind and solar, are suitable alternatives to fossil-based electricity generation. Thus, their share in global electricity generation is projected to rise substantially due to the improvement of wind and solar generation capacity [35,36]. Based on this background, various methods of the mathematical models and technical specifications were applied to the renewed energy sector for analyzing photovoltaic (PV), wind, diesel, converters, and batteries. Marra & Colantoni, (2021) [40] used a panel vector autoregressive mathematical technique to investigate the path to renewable energy consumption in the European Union through drivers and barriers. They argued that, policy inflexibility has positive direct and indirect effects on renewable energy. Moreover, Seker & Kahraman [37] use a two-stage MCDM model integrating Analytic Hierarchy Process (AHP) and Multiplicative Multi-Objective Ratio Analysis (MULTIMOORA) methods to select the most appropriate solar PV panel manufacturer for solar power plants in Turkey. They mentioned that the used method produces consistent and reasonable results in selecting the most appropriate solar PV panel manufacturer for the solar power plants considering the cost, environmental, efficiency, and technical indices.

Regarding wind energy, Murcia, et al. [38] indicated that no model can fully describe the auto-correlation function of the wind speed at a single point. However, Clark et al. (2022) [39] established a set of surrogate models from aeroelastic simulations to estimate power production and bearing lifetime over a defined set of wind conditions, and optimize plant layout for a multi-objective, COE-like metric, balancing reliability, and power production. Moreover, they argued that reliability and power production can be competing objectives, depending on the worked conditions and the result of different optimal layouts.

Akpan (2015) [41] studied electricity access in Nigeria by using three options: grid-extension, mini-grids, and stand-alone system. He applied the network planner technique in the analysis and found that grid-extension is the least-cost option for Nigeria. Likewise, Gani (2021) [42] applies stochastic impacts regression on population, affluence, and technology (STIRPAT) for examining the supply-side effect of energy generation from fossil fuels (coal, natural gas, and oil) on environmental quality. His findings revealed strong adverse effects of agriculture and industrial intensification on environmental quality. While Naval et al. [43] proposed a mathematical techno-economic dispatch model to optimizes the hourly schedule of pumping equipment subject to electrical and hydraulic constraints. They tries to minimize the weekly operating costs of a real pumping station depending on solar availability, water levels of ponds, and the hourly cost of the electricity required to meet water demand. They argued that their proposed model contributed well to the improvement, competitiveness and viability of agricultural operations.

In case of KSA, the current electric power generation relied mainly on crude oil. However, in recent years Saudi Government has announced Vision 2030 to restructure it is economy including the energy sector. With reference to the energy sector, the main targets of the vision are to increase the share of renewable energy, mainly solar and wind, by 20%, remove subsidies from oil and electricity, in addition to others. It is noted that electricity consumption has been substantially reduced after the application of the subsidies removal policy. In this regard, it is worth noting that the eastern region of KSA (study area) occupied the third position after western and central regions in terms of energy consumption in the country [44].

1.1.5. *Oil and energy price studies*

On the other hand, oil and energy prices are important factors to be considered in decision making, as they affect crop production in most countries. Contradicting results were obtained by different research on examining the effect of oil and energy prices on agricultural production. While some studies revealed positive effects of oil price changes on optimal production [45] and income, other authors found a negative impact of oil price increase on consumption and investment [46]. However, there are, in fact, long-run effects of oil price forecast on the predictions of some crops, such as sugar prices [47]. Taking energy into consideration, electricity used in irrigation constitutes the lion's share of energy consumption, accounting for 68.5% [48]. Moreover, the combined analysis of energy input and environmental impact is necessary to optimize crop management practices in a production system, reduce the environmental impacts, and promote sustainable development [49]]. In the climate context, subsidy removal from oil and fuel increases input prices, thus reducing CO2 emission in high-income oil-and gas-exporting regions [50]. Despite the low energy prices in some countries, like Kazakhstan, households still spend more than 10% of their income to purchase it [51].

The nomenclature of the variables, equations, coefficients, and other abbreviations used in the study are shown in Table 1.

Table 1
Nomenclature.

Abbreviation	Explanations
J	Denotes to crop activities practiced on the farm.
i	Denotes to resources used.
S	Denote to seasonality analysis of the constraints
Z	The objective of the LP model is proposed to find the cropping combination that has the maximum possible total gross margin.
$\sum j = 1$	Standard summarization notation, for the crop (j).
X_j	The level of the jth farm growing with crops j.
n	Represents the numbers of crops growing (j = 1, 2, 3, ….,n)
$C_{J,}$	Refers to gross margin (objective value) of the jth crop
b_is	Unpaid resources.
SR	Saudi Riyal, the currency of Saudi Arabia.
ha	Hector
a_{ij}	The quantity of the ith constraints (resources).
m	Represents the number of constraints and then i = 1 to m.
b_i	The amount/supply of the ith constraints/resources available.
GM	Gross margin/ha.
GR	Gross returns/ha.
TVC	Total variable costs/ha.
Pj	The unit price of output j.
Qj	Quantity of output j.
ri	The unit cost of the variable input i.
xi	Quantity of the variable input i.
YCA (J):	Yields of crop activities.
OUTP (J)	The outputs prices of crop activities
INP (I)	The inputs price.
WCVC	Working capital to cover variable costs.
Table In (I, J)	The table used for the technical coefficient's barley matrix.
Table LAN (S, J)	Describe the seasonality of labor, labor use (man-day/ha).
Table LAB (S, J)	Land use which is termed as land use (month/ha).
AMLAN	Amount of land available.
WLHI	Wages of hired in- labors.
WLHO	Wages for hired out- labors
PIR	Private interest rate.
COST	Input cost.
XLCA	Level of crop activity
X	Denotes to names of cultivated crop.
LHILB	Level of hired in labor.
CLAB	Cost of labor
LHOLB	Level of hired out labor.
LBR	Level of labor revenue.
CBA	Capital-borrowing activity.
CBC	Cost of borrowing capital
Z	Objective function.
CAPC	Capital constraint.
CAPCS	Computation of capital cost.
REV	Computation of gross revenues.
INCOS	Computation of tradable input costs.
CONST (I)	Availability number of constraints.
COSTL(S)	Land constraint.
LANCS (S)	Labor constraint.
ALBC	Computation of labor cost.
LABR	Computation of labor revenue.
OBJFUN	The objective function for the Z estimator.
NIPC	Nominal input protection coefficient.
NPOC	Nominal input production coefficient.
EPC	Effective protection coefficient.
SRP	Subsidies ratio to Producer.
PCR	Private cost ratio.
PC	Profitability coefficient.
DRC	Domestic resource cost ratio.
PPC	Private profit coefficient.
CBR	Cost-benefit ratio.
PCR	The private costs ratio.
DCR	The domestic costs ratio.
DUC	Domestic unit cost.
EUC	Export unit cost.

Source: Authors' formulation, 2022.

2. Material and methods

2.1. Study site

This study was undertaken in Al-Ahsa province, located in south-eastern KSA, about 65 km from the Arabian Gulf, at latitude 25° 37′ 12'' and 25° 20′ 24'' N and 49° 32′ 24'' and 49° 46′ 48'' E. The province occupies an area of about 530,000 km^2, representing 68% and 24% of the total area of the eastern region and the whole country, respectively. It includes five oases: Northern, Eastern, Alsifah, Um-Kharasana, and Ein-Maragan Oase. The desert climate prevails in the area with cold and relatively dry weather in the winter and a hot dry climate in the summer. The region registered the highest temperature in the world, 50 °C, in August 2020, [52]. The average annual rainfall in the region is 8 ml. The date palm tree has emerged as an important crop in the region. Al-Ahsa province is famous for being one of the largest date producers in the world, boasting over 2 million palm trees [52]. According to the statistical annual book of the KSA Ministry of Health [53]. the total population of Al-Ahsa is 914,300 people (2018 census). About 93% of them engage in agricultural production-related activities.

2.2. Farming evidence

Results of the descriptive statistics are reported in Tables 2 and 3. The average farm size in the surveyed region is 3.03 ha. However, the cultivated crop area is restricted to 2.08 ha, and the rest of the land (0.95 ha) is devoted to animal raising. Male farmers constitute the most share (94%) of the total farmers in the study area-such phenomenon is common in the KSA. The average age of the respondents is 43.7 years with long experience in practicing agriculture (11 years) and large family size (the average size of the family is 6 persons per household).

Economic growth is positively related to male education and negatively related to female education [54]. Considering the education level in the region, a considerable amount of the farmers (25%) is unschooled and 75% of them are educated, but only 10.5% of them had received a university education. Furthermore, the results revealed that the feature of the farms' owners is a mixture of own and hired lands. The average annual income reimbursed from the farms under the existing situation in the area is somehow rational (RS 81490).

Table 2
Summary of descriptive statistics of the demographic factors of farmers in Al-Ahsa province, KSA.

Quantitative factors				
Indicators	Numbers	% From total	(M ±SD)[a]	(Min-Max)[a]
1- Farmer's age (in the year)	100	100	(43. ±20.80)	(20–90)
2- Farm experience (years in practicing agricultural activities)	100	100	(11 ± 120.99)	(1–50)
3-Family size (in person)	100	100	(6 ± 98.34)	(2–19)
4. Average farm size (in ha.)	100	100	(3.03 + 78.54)	(1–7.2)
Qualitative factors				
Indicators	Numbers		% From total	
1- Gender				
Male	96.0		94.0	
Female	4.0		6.0	
2- Education				
Reading and writing	75.0		75.0	
Illiterate	25.0		25.0	
3- Having other jobs				
Yes	65.0		63.7	
No	35.0		34.3	
4- Marital status				
Married	85.0		85.0	
Single	15.0		15.0	

[a] M: Mean; SD: Standard Deviation. * Min: minimum; Max: maximum.
Source: Study survey, 2018/2019

Table 3
Summary of descriptive statistics of crop production in Al-Ahsa province, KSA.

Crops' Cultivated area in ha.			
Crops	Mean ± STD	(Min)	Max
1. Tomatoes	0.23 ± 42.23	0.02	0.45
2. Potatoes	0.5 ± 45.25	0.12	1.00
3. Ladyfinger	0.44 ± 85.52	0.31	0.89
4. Eggplant	0.14 ± 89.25	0.02	0.19
5. Zucchini	0.09 ± 122.14	0.001	0.21
6. Onion	0.42 ± 56.23	0.11	0.78
7. Barley	0.01 ± 25.56	0.002	0.24
7. Alfalfa	0.25 ± 0.12	0.03	0.50
Crops' production in ha.			
Crops	Mean ± STD	(Min)	Max
1. Tomatoes	(90 ± 12.023)	45	150
2. Potatoes	90 ± 13.69	43	149
3. Ladyfinger	67 ± 3.78	21	145
4. Eggplant	55 ± 123.47	14	85
5. Zucchini	21 ± 89.56	12	67
6. Onion	89 ± 76.58	50	250
7. Barley	41 ± 175.02	32	68
8. Alfalfa	35 ± 56.123	24	45

Source: Study survey, 2018/2019.

On the other hand, the self-finance method is the dominant manner in the region. A majority of farmers self-finance their farming activities (94.7%), but few of them receive bank loans (5.3%), hence self-financing for crop production is a common feature in developing countries [55]. Results also showed that a huge sum of farmers (84%) is involved in other jobs alongside farming activities, mainly as public secondary school teachers. According to their statement, practicing two jobs is tedious work, but depending on crop production is not commercially profitable.

In areas where water is a limiting factor in crop production, deficit irrigation may be practiced [56]. Results revealed that most farmers (55%) in the area used wells and treated-drainage water to irrigate their farms, hence, the farmers adopt various methods of modern irrigation (drip and spray).

Most farmers (95%) in the study area cultivate date-palm trees as the primary activity in addition to other mixed crops. The major crop combinations grown on the farms are vegetables, cereals, fodder, and fruits, besides some minor crops cultivated in the marginal lands, such as winter flowers, but in fewer percentages (5%). Although rice stands as the main foodstuff in the KSA, the government prohibits its cultivation because it requires a huge quantity of irrigation water. Despite that, a small percentage of farmers cultivated it (8%).

Regarding the laborers used, the realistic results showed that various types of laborers are used in crop production in the region. They can be written in order as family laborers, permanent laborers, seasonal laborers, and specialized laborers.

2.3. Data nature and sources

The research was based mainly on primary data collected directly from farmers in the study area, in addition to collected supportive secondary data. Multistage random sampling technique was used for collecting primary data from 100 respondents using a structured questionnaire. Three stages were used in data collection. In the first stage, two zones were selected purposively on being the main crop production areas: Northern and Southern zones. In the second stage, one oasis was chosen randomly, Um-Kharasana and Ein-Maragan Oasis from each zone, respectively. In the last stage, 100 farmers were chosen randomly from the two oases in proportion to their weight in the sample size (Equation (1)). The total sample size was calculated by using an online sample size calculator [57] at 95% confidence level, 5% error, and a total population of 2000 farmers. Accordingly, the sample size was found to be 100 farmers. Furthermore, the sample for each locality was calculated according to the following equation:

$$L = \frac{S}{N} \times n \tag{1}$$

Whereas:

L = sample size for each locality; S=Numbers of farmers cultivating vegetables, forages, and cereals crops in each locality; N = total numbers of farmers specialized in Al-Ahsa province and n = 100.

The primary data, which was collected during the 2018-19 agricultural season, covered the information on types of crop production, agricultural activities, crop consumption, and selling, farmers' socio-economic characteristics, land ownership status, size of agricultural land, types of labor, and water use systems. Likewise, the information covered, inputs, such as the quantity and prices (fertilizers, pesticides, oil, energy, etc.), and outputs (quantity produced and prices) at the farm level. The study incorporated some secondary data on crop cultivation with the collected primary one. The secondary data used in this study was derived from the government [1,4] and other relative institutional sources [5,58] Such methods are practiced in literature, for instance, Souza et al. [59], used combined primary data and secondary data to analyze the social and private accounting evaluation of rice production chains in Brazil and Uruguay.

2.3.1. *Analytical techniques*

Different analytical techniques were used in the study to achieve the stated objectives: correlation coefficients analysis and the combined tools of LP and PAM. However, it is noteworthy to mention that the General Algebraic Modelling System (GAMS) and SPSS software were used in performing the analyses.

2.3.1.1. LP mathematical model. Linear Programming (LP) model was used to determine the optimal crop combination in the study area. In fact, the optimization model plays a vital role in modern economics; accordingly, the LP approach is the most suitable technique for the construction of the optimal crop combination at micro levels [60–62]. Moreover, in linear programming, both the objective and the constraints relationships are expressed as linear functions of decision variables [63].

The LP model was applied in this study to help farmers make the right decisions in allocating their limited farm resources, such as capital, land, labor, water, and other inputs in such a way to optimize their farm returns. In the case of our study, the LP model for crop optimization illustrates mathematically, and takes the following formulations:

$$\text{Max} \quad z = C_1X_1 + C_2X_2 - - + C_nX_n \tag{2}$$

Whereas the standard summarization notation ($\sum_{j=1}$) is used [47] and then, the following general algebraic notation can be generated as:

$$Z = \left(\sum_{j=1}^{n}\right) C_jX_i \tag{3}$$

Such that:

$$\sum_{j=1}^{n} a_{ij}\ X_j \ \leq b_i \ , \text{for} \ \ i = 1 \ \ \text{to} \ \ m \tag{4}$$

and,

$$X_j \ \geq 0 \ \ \text{for} \ \ j = 1 \ \ \text{to} \ \ n \tag{5}$$

Whereas:

The per unit return to the unpaid resources (b_is) for the jth activity; in Saudi Riyal (SR) per hector (ha); a_{ij} in this study are fix and variable inputs, the a_{ij} values are referred to as technical coefficients or input-output coefficients (land, water, fertilizers, pesticides, oil, energy, etc.) necessary to produce one unit of the jth crop.

b_i includes natural resources (ha of land or cubic meter of water), human resources (hours of labor), and operation resources kg of consumed inputs (e.g. fertilizers, pesticides, etc.), where i = 1, 2, 3, …., m.

The objective of the LP model is proposed to find the cropping combination that has the maximum possible total gross margin, Z, however, ensures that there are no violations of any of the fixed resource constraints or inclusions of any negative crop activity levels. Equations (2) and (3) specify the objective function as the maximization of the summation of the net returns (C_j) from a set of activities (gross margin of the crop), times the number of units of each process in the solution, X_j [64,65]. Hence, the study combines an LP model with PAM structures to analyze the collected data utilizing the GAMS, which is a high-level modeling system for mathematical optimization [64,65]. Once the LP model for crop production is built, the gross margin analysis will be constructed.

2.3.1.2. Gross Margin Analysis (GMA). The gross margin for the cultivated crop is usually estimated by subtracting the gross returns from the total variable costs [66]. In this study, the gross margin for a crop was computed on a per ha basis and expressed in SR. The general formula of the gross margin analysis can be written as follows:

$$\text{GM} = \text{GR} - \text{TVC} \tag{6}$$

Which subject to:

$$\text{GM} = \sum P_i\ Q_j - \sum r_i x_i \tag{7}$$

2.3.1.3. GAMS LP model. The common construction of the proposed GAMS model for this study is well-illustrated and organized as follows:

Sets:

J: crops activities; I = resources used and s: seasonality analysis of the constraints.

Parameters: This is a key to specify the begging of exogenous constant variables of the model for a scalar [67]. Usually, the parameters are denoted with CjXi Equation (3) and bi in Equation (4). Some parameters used in the study's model are YCA (J), OUTP (J), and INP (I) Furthermore, the parameter of WCVC is introduced in the model.

Tables: The tables in GAMS use keywords to indicate the begging of the data array [53], which match aij (Equation (4)). Three formulas of matrix tables are introduced in the model, the first table classifies as Table In (I, J) which includes: land, seeds, fertilizers, oil, energy constraints, etc.). The second and third tables describe the seasonality of labor and land use which are termed LAN (S, J) and LAB (S, J)

Scalars: AMLAN; WLHI; WLHO and PIR.

Variables: The variables used are endogenous one as follows

Revenue: gross revenue from crop activities; COST; XLCA (X denotes for names of the cultivated crop); LHILB; CLAB; LHOLB: LBR; CBA; CBC; and Z: objective function.

Positive variables: The positive variable of activities (j) means that all optimal levels of activities should be positive values. XLCA, LHILB, and LHOLB;

Equations: The equations were written according to GAMS notation. For capital constraints equations, the equation is expressed as: CAPC and CAPCS; then

$$\text{WCVC} \ \ (\text{J}) = \text{sum} \ \ (\text{I}, \text{INP} \ \ (\text{i})^*\text{IN} \ \ (\text{I}, \text{J}) \tag{8}$$

$$\text{CAPC....SUM} \ \ (\text{J}, \ \ \text{WCVC} \ \ (\text{J})^*\text{XLCA} \ \ (\text{J})) = \text{L} = \text{CBA} \tag{9}$$

$$\text{CAPCS} \ \ .. \ \ \text{CBC} \ \ = \text{E} = \ \ \text{CBA}^*\text{PIR} \tag{10}$$

Whereas the main equations are defined as follows:

$$\text{REV..REVENUE} = \text{E} = \ \ \text{SUM} \ \ (\text{J}, \ \ \text{YCA} \ \ (\text{J})^* \ \ \text{OUTP(J)}^* \ \ \text{XLCA(J)}). \tag{11}$$

$$\text{INCOS.. COST} = \text{E} = \text{SUM}((\text{I},\text{J}), \text{IN}(\text{I},\text{J}) * \text{INP}(\text{I}) * \text{XLCA}(\text{J})). \tag{12}$$

$$\text{ALBC .. CLAB} = \text{E} = \text{SUM}\ (\text{S}, \text{WLHI} * \text{LHILB}(\text{S})). \tag{1}$$

$$\text{LABR.. LBR} = \text{E} = \text{SUM}\ (\text{S}, \text{WLHO} * \text{LHOLB}(\text{S})) \tag{14}$$

$$\text{COSTL(S)..SUM}\ (\text{J},\ \text{LAN}\ (\text{S},\text{J}) * \text{XLCA}(\text{J})) = \text{L} = \ \text{AMLAN}. \tag{15}$$

$$\text{CONST (i) … Sum (J, In (I, J)*XLCA (J)) = L = B (I)} \tag{16}$$

$$\text{LANCS(S).. SUM(J, LAB (S,J)* XLCA(J))} = \text{L} = \ \text{AMLAN} + \text{LHILB(S)} - \text{LHOLB(S)}. \tag{17}$$

Finally, the OBJFUN equation, expresses as:

$$\text{OBJFUN..Z} = \text{E} = \text{REVENUE} - \ \text{COST} - \text{CLAB} + \text{LBR} - \text{CBC}. \tag{18}$$

2.3.1.4. PAM model. Policy Analysis Matrix (PAM) was used to identify which of the studied crops are domestically efficient and internationally competitive and to what extent the government intervenes in crop production (subsided or taxed).

The PAM approach was modified and broadly used in most economic studies [68–70]. The PAM structure is proven in Table 4.

According to Monke and Pearson [71], PAM computation was built on two equations:

(1) **Profit** = revenue – costs, and **(2) Policy effect** = private price – social price, thus, two types of profits and policy effect result as follows:

Profits:

(a) Private profits: D = A-(B + C), (b) Social profits: H = E– (F + G)

Policy effect resulting:

(a) Revenue transfer: I = A – E.
(b) Input transfer: J = B – F.
(c) Domestic transfer: K = C – G.
(d) Net policy transfer: L = D – H

Moreover, important economic policy parameters were obtained from the PAM (for instant coefficients and indicators).

Two types of coefficients are estimated protection and subsidies coefficients.

(1) Protections coefficients
(a) NIPC =B/F.
(b) NPOC = A/E.
(c) EPC = (A-B)/(E-F).
(2) Subsidies coefficient
(a) SRP= (D – H)/E = L/E.
(b) PCR = C/(A – B).
(c) PC = (A – B – C)/(E − F – G) = D/H.

Table 4
PAM framework.

Prices	Revenues	Costs of tradable input	Cost of non-tradable factors (domestic)	Profits
Prices private	A	B	C	D
Social prices	E	F	G	H
Transfer	I	J	K	L

Source: [57].

Moreover, extra indicators are estimated.

(1) Comparative advantage indicators
(a) DRC = G/(E − F).
(b) PPC = (A -B - C)/(E − F - G).
(c) CBR = {(F + G)/E)}.
(2) Competitiveness indicators
(a) PCR = |C|/(A–|B|).
(b) DCR = |G|/(E–|F|).
(c) DUC = (B + C)/A.
(d) EUC = (B + C)/E.

The data applied for constructing the PAM Table was composed of both tradable and non-tradable inputs. Tradable inputs comprise the inputs, which can be traded internationally in the world market, such as insecticides, fertilizers, seeds, etc., while non-tradable inputs are mainly domestic factors that are not traded internationally (land, labor, capital, etc.) but locally at the market prices. This study employed data on crops' outputs, imported inputs, and market prices (for both inputs and outputs) with supplementary data, such as exchange rate, import, and export tariffs.

The private prices for tradable outputs and inputs in this study were computed at domestic market prices, while social prices and import price were computed in terms of cost of insurance and freight (CIF) prices for importable and free on board (FOB) prices for exportable (used as the reference prices in the study). Furthermore, these two prices are converted to local prices (Saudi Riyal (SR) at the shadow exchanges rate using the exchange rate in US$ (one US$ = 3.75 RS) at the time of the study.

3. Results and discussions

3.1. Relationship between demographic factors and studied crop returns

The matrix correlation analysis was established to identify the relationships between demographic factors, crop returns, and oil consumption. As shown in Table 5, the result indicates a significant correlation between some demographic factors and crop returns in the study area.

The results of the correlation analysis (r and p-value) that were used to examine the relationship between farmers' socioeconomic factors and crop returns are displayed in Table 5. It is noticed that there is an inverse correlation 43%, between farmers' age and onion returns (r = 0.436, p<1%), however, a positive one with tomatoes, 38% (r = 0.380, p>5%) and eggplant, 44% (r = 0.441, p<1%). Contrarily to the expectations, marital status shows a negative relation with ladyfinger returns, 39% (r = 0.388, p<15%). It is also clear from Table 5 that practicing other jobs reflects a positive response with tomatoes, 55% (r = 0.353, p<5%) and eggplant returns, 52% (r = 0.523, p<1%). Family size positively stimulates tomato (r = 0.554, p<1%), ladyfinger, 44% (r = 0.443, p<5%) and eggplant returns, 55% (r = 0.558, p<1%) and negatively affects onions, 39% (r = 0.396, p<5%). These results confirmed that returns from tomatoes and eggplants are highly influenced by the socioeconomic factors in comparison to other crops.

Furthermore, there is a significant correlation between the farmers' demographic characteristics and oil consumption, as illustrated in Table 6. There is a positive relationship between farmers' engagement in other jobs and oil consumption in tomato cultivation, 35% (r = 0.353, p<5%). Likewise, farmers' age and other jobs has a statistically positive and significant relationship with the oil consumption of ladyfingers, 37% (r = 0.373, p<5%) and 48% (r = 0.481, p<1%); respectively. Moreover, ladyfingers' oil consumption reflects a negative relation with family size, 36% (r = −0.360, p<5%) and farmers' experience, 33% (r = −0.339, p<1%). Educational status mainly influences decision-making [72]. Table 6 reveals that education reflects a positive association with ladyfinger oil consumption (r = 0.583,58 p>1%) and a negative

Table 5
Matrix correlation analysis of the demographic factors and crop returns in the KSA.

Variables	Tomatoes returns	Potatoes returns	Ladyfinger returns	Eggplant returns	Zucchini returns	Onion returns	Barley returns	Alfalfa returns
Gender	−0.142	0.039	−0.11	−0.301	−0.100	0.026	0.176	0.045
	(0.396)	(0.817)	(0.520)	(0.067)	(0.550)	(0.879)	(0.289)	(0.788)
Age	0.380*	0.116	0.030	0.441**	−0.15	−0.436**	0.159	−0.280
	(0.019)	(0.487)	(0.867)	(0.006)	(0.928)	(0.006)	(0.341)	(0.089)
Education	−0.221	0.188	−0.84	0.065	−0.178	0.179	−0.067	0.173
	(0.182)	(0.260)	(0.643)	(0.698)	(0.286)	(0.283)	(0.689)	(0.300)
Marital status	−0.175	0.080	−0.388*	−0.392	−0.220	0.275	0.030	0.134
	(0.294)	(0.631)	(0.026)	(0.015)	(0.228)	(0.094)	(0.859)	(0.422)
Other jobs	0.353*	0.052	0.256	0.523**	0.022	−0.165	−0.068	−0.258
	(0.030)	(0.758)	(0.151)	(0.001)	(0.897)	(0.322)	(0.684)	(0.118)
Family size	0.554**	0.369	0.443*	0.558**	0.114	−0.396*	−0.160	−0.308
	(0.00)	(0.025)	(0.011)	(0.000)	(0.502)	(0.015)	(0.343)	(0.063)
Farming experiences	0.288	0.195	0.219	0.276	0.157	−0.0115	0.080	0.023
	(0.079)	(0.240)	(0.222)	(0.094)	(0.347)	(0.490)	(0.633)	(0.890)

Note: Numbers enclosed in parenthesis are significant value.
**. r (correlation coefficient) is significant at the 0.01 level (2-tailed).*. r is significant at the 0.05 level (2-tailed).
Source: Study survey, 2018/2019.

Table 6
Matrix correlation analysis of the demographic characteristics and crops' oil consumption.

Variables	Oil consumption in crops and fodder cultivations							
	tomatoes	potato	ladyfinger	eggplant	zucchini	onion	barley	alfalfa
Gender	−0.139	0.073	0.186	- 0.011	0.052	−0.012	−0.139	−0.025
	(0.405)	(0.663)	(0.263)	(0.950)	(0.758)	(0.941)	(0.406)	(0.884)
Age	0.040	0.187	0.373*	0.125	−0.330	−0.024	0.090	0.119
	(0.811)	(0.261)	(0.012)	(0.453)	(0.043)	(0.886)	(0.593)	(0.476)
Education	−0.330*	−0.022	0.583**	0.012	0.228	0.102	0.063	0.080
	(0.043)	(0.894)	(0.00)	(0.942)	(0.169)	(0.543)	(0.686)	(0.635)
Marital status	−0.263	0.113	0.231	−0.263	0.147	0.148	0.060	−0.104
	(0.110)	(0.500)	(0.163)	(0.110)	(0.378)	(0.377)	(0.719)	(0.534)
Jobs	0.353*	0.052	0.481**	0.014	0.022	−0.165	0.068	−0.258
	(0.030)	(0.758)	(0.005)	(0.941)	(0.897)	(0.322)	(0.684)	(0.118)
Family size	0.140	−0.031	−0.360*	0.144	−0.198	−0.132	−0.144	0.153
	(0.409)	(0.854)	(0.029)	(0.397)	(0.240)	(0.437)	(0.394)	(0.366)
Farming experiences	0.282	0.077	−0.339**	0.216	−0.140	−0.103	0.188	0.086
	(0.086)	(0.646)	(0.093)	(0.192)	(0.402)	(0.537)	(0.259)	(0.609)

Note: Numbers enclosed in parenthesis are significant value.
**. r is significant at the 0.01 level (2-tailed).
*. r is significant at the 0.05 level (2-tailed).
Source: Study survey, 2018/2019.

Table 7
Interlinks between demographic characters and crops' energy costs.

Variables	Gender	Age	Education	Marital status	Other jobs	Family size	Farming experience	Energy price
Gender	1							
Age	−0.10	1						
	(0.54)							
Education	0.34*	−0.47**	1					
	(0.04)	(0.00)						
Marital status	0.08	0.32*	0.01	1				
	(0.62)	(0.05)	(0.94)					
Jobs	−0.14	0.55**	−0.24	−0.25	1			
	(0.40)	(0.00)	(0.15)	(0.13)				
Family size	−0.23	0.66*	−0.24	−0.41*	0.48**	1		
	(0.18)	(0.00)	(0.16)	(0.01)	(0.00)			
Farming experience	−0.12	0.64**	−0.25	−0.21	0.15	0.59**	1	
	(0.49)	(0.00)	(0.14)	(0.21)	(0.38)	(0.00)		
Energy prices	0.45**	−0.04	0.34*	−0.13	0.71**	−0.13	−0.46*	1
	(0.00)	(0.83)	(0.04)	(0.45)	(0.00)	(0.44)	(0.00)	

Note: Numbers enclosed in parenthesis are significant value.
**. r is significant at the 0.01 level (2-tailed).
*. r is significant at the 0.05 level (2-tailed).
Source: Study survey, 2018/2019.

one with tomato oil consumption ($r = -0.330$, $p<5\%$), but with small magnitude. This result confirmed by Safa et al. and Mathanker & Hansen [73,74], find a significant and direct correlation between fuel diesel consumption, yield, and farmers' education.

On the other hand, the amount and value of energy have been calculated for the whole farm, because it was very difficult to be estimated for each crop. The relationship between consumed energy costs and farmers' demographic characteristics is presented in Table 7. It is clear from Table 7 that, energy costs is significant and positively correlated with gender, 45% ($r = 0.451$, $p<1\%$), education, 34% ($r = 0.340$, $p<5\%$), and other jobs, 71% ($r = 0.711$, $p < 1$); but, has a negative association with the number of years practicing farming activities, 45% ($r = 0.459$, $p<5\%$), even though the other categories of demographic factors show no response on energy costs.

It is very clear from the results of correlation analysis that some demographic factors have a strong correlation with crop returns and farms' oil cost and consumption under the current situation of oil and energy subsidy removal. Thus, certain measures are needed for changing farmers' attitudes and beliefs towards utilizing farms' resources efficiently, particularly energy and oil, to improve their returns.

3.2. *Financial analysis of the farms*

The nature and type of the farming system in the study region revolves around vegetables and fodder production. It is noticeable here that forage production, which is mainly confined to barley and alfalfa, is generally used to feed farm animals.

The assessment of farm-level budgets needs the estimation of the prices for both resources and products [75]. It appears from the displayed gross margin analysis in Table 8 that all cultivated crops in the study area are financially profitable at perceived market prices. However, tomatoes gained the highest gross margin and constitute about 43% of the total farmers' net return, followed by potatoes (23%) and ladyfingers (19%). Moreover, results revealed that potato crop yield has declined substantially by 24% after subsidy removal compared to Ali et al. [76]. On the other hand, barley occupied the last position in terms of the crops' share in the farmers' net returns (0.3%). These results contradict the findings of Ali et al. [76] in their study, "vegetable production in Saudi Arabia: protection coefficients and relative efficiency," which was performed in the Al-Ahsa province before subsidies removal. They found that eggplant gained the highest gross margin, while zucchini and ladyfingers comprised the lowest.

3.3. *Optimal crop level, production, and returns*

The LP maximization model for optimal cropping pattern in the study area was run under the actual situation of energy and oil, subsidy removal, and their consequences on input prices increasing. It is perceivable from the farmers' actual practices in the field that considerable farm area is devoted to potato cultivation. That is, the potato crop covers the largest cultivated area, while barley comprises the smallest.

Results of the LP optimal model showed that lettuce, rice, melon, carrot, cauliflower, and cucumber, although cultivated in the farms, did not enter the optimal model. This is particularly true if known that such crops are cultivated as minor crops in the region.

On the other hand, it's observable from the LP model that the net returns from the optimal model (261456.3 RS) exceed the actual results (70174.9 RS) by about four-fold. It is also noticeable that the optimal level of crop combinations under the prevailing oil and energy prices is composed of potatoes (0.18 ha), ladyfinger (0.68 ha), eggplant (0.49 ha), zucchini (0.10 ha), onion (0.13 ha), barley (0.04 ha), and alfalfa (0.46 ha), respectively (Table 9). However, it is worth mentioning that although tomatoes recorded the highest net returns, it disappears from the optimal solution due to the seasonality of constraints. In the same vein, potato crop records a great dropping in the actual cultivated area by (-87.27%), followed by onions (-51.90%), (Table 9). On the other hand, the optimal land areas devoted for ladyfinger, eggplant, zucchini, barley, and alfalfa expanded by 12.87%, 55.63%, 2.70%, 64.91%, and 29.58%, from the actual ones, respectively.

But when considering the optimal solution of crop production, potatoes comprise the highest reduction (33.11%), followed by onion (15.25%). Whereas zucchini shows the highest in crop variability (71.07%), followed by barley (55.96%).

Regarding crop selling and consumption, the quantities of crops selling in the optimal solution for potatoes and onion decreases substantially by 60% and 71% from the actual one; respectively. Similarly, the consumption quantities of the two crops highly decreased by 19.69% and 39.56%; respectively.

Furthermore, returns from alfalfa and barley selling are significantly improved by more than 99% and 89% compared with the actual one, respectively. Likewise, ladyfingers, eggplant, and zucchini show a progressive rise in the optimal amount of the crop balance.

In case of changes in the farms' constraints in the optimal solution, it is noticeable that the variability of energy consumption witnesses the highest substantial reduction compared to the actual one (83.88%). This

Table 8

Gross margin analysis of the cultivated crops on the farm (2018/2019).

Items	Majors Crops							
	Tomatoes	Potatoes	Ladyfingers	Eggplant	Zucchini	Onion	Barley	Alfalfa
Variable costs (SR/ha):								
1. Land preparations	2500	1600	2400	1800	500	122	1200	950
2. Material inputs	2500	3285	2400	5250	450	5590	900	450
3. Harvest	1000	1530	2000	1500	650	2000	1520	1500
4. Energy, oil and other costs	1520	1520	1500	1000	520	750	520	450
TVC (SR/Ha)	7520	7935	8300	9550	2120	8462	4140	3350
%	(0.15%)	(0.15%)	(0.16%)	(0.19%)	(0.04%)	(0.16%)	(0.08%)	(0.07%)
TVC (US$/ha)	2005.33	2116	2213.33	2546.67	565.33	2256.53	1104	893.33
Returns:								
1. Average yield (ton/ha)	90	90	67	55	21	89	41	35
2. Average price (SR/ton)	228	164	208	208	120	110	80	120
3. Yield return (SR/ton)	20520	14720	13936	11440	2520	9790	4200	4200
4. Crop residues (SR/ton)	50	12	18	17	0	0	25	42
GR (SR/ha).	20570	14732	13954	11457	2520	9790	4225	4242
GM (SR/ha).	13050	6797	5654	1907	400	1328	85	892
%	(0.43%)	(0.23%)	(0.19)	(0.06%)	(0.01%)	(0.04%)	(0.003%)	(0.03)
GM (US$/ha)	3480	1812.53	1507.73	508.53	106.67	354.13	22.67	237.87

Source: Study survey, 2018/2019.

Table 9

Optimal cropping patterns under soaring oil and energy prices (2018/2019).

Crop activity	Cultivated areas in ha		Variability (%)	Production (in ton)		Variability (%)
	Actual level	Optimal level		Actual level	Optimal level	
1. Tomatoes	0.23	0.00	−100.00	90.00	0.00	−100.00
2. Potatoes	0.50	0.18	−47.06	90.00	45.23	−33.11
3. Ladyfingers	0.44	0.68	21.43	67.00	85.53	12.15
4. Eggplant	0.14	0.49	55.56	55.00	120.23	37.23
5. Zucchini	0.09	0.10	5.26	21.00	124.20	71.07
6. Onion	0.42	0.13	−52.73	89.00	65.45	−15.25
7. Barley	0.01	0.04	60.00	41.00	145.21	55.96
8. Alfalfa	0.25	0.46	29.58	35.00	149.12	61.98
Crop activity	**Quantities of sold crop**		**Variability (%)**	**Quantities of crop consumption by household**		**Variability (%)**
	Actual level	**Optimal level**		**Actual level**	**Optimal level**	
1. Tomatoes	65.00	0.00	−100.00	25.00	0.00	−100.00
2. Potatoes	50.00	12.50	−60.00	40.00	20.13	−19.69
3. Ladyfingers	30.90	45.58	19.19	36.10	120.3	53.84
4. Eggplant	20.00	78.25	59.29	35.00	75.25	36.51
5. Zucchini	17.00	98.01	70.44	4.00	25.40	72.79
6. Onion	70.25	12.00	−70.82	18.75	8.12	−39.56
7. Barley	41.00	145.21	55.96	–	–	–
8. Alfalfa	35.00	149.12	61.98	–	–	–
Resource	**Constraints/Resource use**			**Objective function value (in SR)**		
	Actual level	**Optimal level**	**Variability (%)**	**Actual level**	**Optimal level**	**Variability (%)**
1. Total land	2.08	2.08	0.00	70174.85	261456.29	57.68
2.Total labor (man-day/ha)	65005.00	186853.90	48.37			
3. Seed (in kg)	580.00	452.00	−12.40			
4.Water requirements (m3)	856523.00	78523.00	−83.21			
5. Fertilizer (in kg)	500.00	450.20	−5.241			
6.Energy (watt/farm)	160000.00	14025.25	−83.88			
7.Oil (litre/farm)	1450.00	2588.72	28.20			

Source: LP Model results, 2018/2019.

result is in line with Aryanpur et al. [77], who stated that subsidy removal reduces energy consumption thus helps in preventing global warming. Adding to the water requirements is a reduction by (83.20%) in comparison to the actual solution. Likewise, variability in seeds (12.40%) and fertilizers (5.24%). Conversely, the variability in the number of labor-hours and oil used to rise by (48.37%) and (28.19%) compared with the actual one; respectively. It is also noted that land constraint is completely used in the optimal solution. This result is in line with the findings of Sofi et al. [78], who concluded that the amount of land used in the optimal solution is much greater than actually cultivated land.

Polthanee [79], argues that water stress plays a great role in the reduction of crop yield. The quantity of the water requirement for cultivated crops in the optimal LP results in a decrease of more than 83% from the practiced one.

It is important to draw attention to the fact that the amount of water used in crop production is very difficult to measure by farmers in the study area because most crops are usually cultivated in the winter rainy season, thus, water constraint in the model was measured from secondary data and introduced in the LP model. Based on MoEWA [1], the total demand for water in the province was estimated in 2018 to be more than 25 billion cubic meters, including 13% for municipal purposes, 5% for industrial purposes, and 82% for agricultural purposes. However, it is worth mentioning that the total water requirement introduced in the LP model was 856523 M3, and the irrigation water required for each crop are as follows: alfalfa = 4102.9; potatoes = 64.09; tomatoes = 73.45; eggplant = 72.5; ladyfingers = 65.6; onions = 75.6; zucchini = 75.23, and barley = 3142.081 [1].

Conversely, results of the optimal model showed that water requirements reach their peak in the summer season (May and July months). But, due to seasonality, the labor constraint reaches its highest records in October and January for potatoes and ladyfingers, while barley and alfalfa register peak of labor used in October (cultivation period) and April (harvesting period). According to the LP results, farmers in the study area do not use their resources efficiently under the current situation of subsidy removal. Accordingly, extension services are needed to help farmers improve their returns.

3.4. Incentive of the economic policy on competitiveness

The analysis of competitiveness and economic efficiencies, which affects the cost and profitability of crop production techniques, should take into account the government intervention policies such as currency exchange rates, interest rate, social contributions, subsidies, taxes, and other duties [80]. The impact of the economic policy on the protections and subsidies coefficients of the crop outputs is illustrated in Table 10. It is obvious that farmers cultivating tomatoes, ladyfinger, eggplant, zucchini, barley, and alfalfa received indirect subsidized and competition on an exportable basis (NIPC >1). On the other hand, potato producers are negatively protected, as the private price of potatoes outputs is less than its parity (NIPC (<1). This result contradicts the findings of Ali et al. [60], which was conducted in the same region of the KSA,

Table 10

Parameters of the crop protection and subsides coefficients.

Crops	Protection coefficients			Subsidies	
	NIPC	NOPC	EPC	SRP	PC
1. Tomatoes	1.49	0.67	0.57	−0.38	0.51
2. Potatoes	0.80	0.53	0.51	−0.43	0.47
3. Ladyfingers	1.31	0.44	0.36	−0.55	0.32
4. Eggplant	1.11	0.96	0.92	−0.01	0.99
5. Zucchini	1.00	0.56	0.41	−0.42	0.09
6. Onion	1.10	0.93	0.86	−0.12	0.77
7. Barley	2.09	0.67	0.60	−0.42	0.54
8. Alfalfa	1.10	0.07	0.05	−0.79	0.03

* Note: Interpretation of PAM coefficients: NIPC, NOPC and EPC >1: imply protection, SRP = positive value implies protection, PC < 1: implies competitiveness.

Source: LP Model results, 2018/2019.

before the removal of the oil and energy subsidies (2016/2017). Likewise, it contradicted the findings of Ali et al. [81] in their "Evaluation of the economic policy of tomato and potato crops in Egypt". They concluded that tomatoes and potatoes are positively protected in Egypt (NIPC <1).

Likewise, the results of PAM show that all cultivated crops in the study area have NOPC values less than one, indicating that importing these crops is more profitable than domestically producing them. According to Ali and Khan [82], the EPC is normally better than NPC as an indicator of incentives. The Effective Protection Coefficient (EPCs) values of the produced crops in the study area are less than unity, implying that producers are not positively protected by the prevailing government policy. Similarly, the negative values of SRPs confirmed that the government had not protected crop production during the surveyed period. In contrast, the profitability coefficient for all cultivated crops in the study area is less than one (PC < 1), indicating that crop production had competitiveness (Table 10).

It is noticeable from Table (11) that the studied crops (tomatoes, potatoes, ladyfingers, eggplant, zucchini, onion, barley, and alfalfa) are domestically efficient and internationally competitive. The recorded values of DRCs are lower than one, which means that crop production had comparative advantages; however, they are not profitable (PPC <1). Moreover, the values of PCR, DCR, DCU, and EUC are less than one (PCR, DCR, DCU, and EUC <1), implying that the produced crops could compete with domestic and international production. Furthermore, all cultivated crops in the study area showed high comparative advantages (CBRs <1). Nevertheless, Bani [83] did not find a clear comparative advantage of the 12 vegetable crops he examined under traditional irrigation systems in Bahrain, while Rashid and Matin [84] found the comparative advantage of pulse crop production in Bangladesh.

Table 11
Comparative advantages and competitiveness.

Crops	Comparative advantage indicators			Competitiveness indicators			
	DRC	PPC	CBR	PCR	DCR	DCU	EUC
1. Tomatoes	0.12	0.51	0.22	0.22	0.12	0.40	0.27
2. Potatoes	0.11	0.47	0.18	0.18	0.11	0.28	0.15
3. Ladyfingers	0.12	0.32	0.19	0.21	0.12	0.41	0.18
4. Eggplant	0.38	0.99	0.54	0.34	0.38	0.53	0.51
5. Zucchini	0.37	0.09	0.54	0.87	0.37	0.93	0.52
6. Onion	0.24	0.77	0.46	0.31	0.24	0.55	0.51
7. Barley	0.05	0.54	0.09	0.15	0.05	0.27	0.18
8. Alfalfa	0.17	0.03	0.19	0.49	0.17	0.68	0.05

* Note: Interpretation of PAM indicators: DRC<1 implies comparative advantage, PPC>1 implies profitable-, CBR<1 implies comparative advantage, PCR, DCU, and EUC<1 imply competitiveness.
PAM results revealed that farmers in the study area need government support to continue in the business and to compete with imported agricultural products.
Source: Model results, 2018/2019.

4. Conclusion

The KSA has undertaken certain policies toward reforming its economic situation, such as subsidy removal from the oil and energy sectors. Accordingly, the effect of subsidy removal on the agricultural sector needs to be deeply investigated. This necessitates conducting a study that aims to determine the optimal cropping pattern in the KSA under soaring oil and energy prices and to examine the comparative and competitive efficiencies of crop production by using combined analytical approaches of LP and PAM. The study reveals that some socioeconomic factors have a strong correlation with crop production. For instance, ladyfinger oil consumption records a statically significant positive relationship with farmers' education and age; however, farmers' jobs show the highest significant and positive correlation. Similarly, education reflects a positive relationship with oil consumption on tomato crop cultivation. On the other side, energy costs show positive relation within gender, education, and other jobs, yet it depicts a negative one with farming experiences. Financially, all crop production is profitable at perceived market prices. However, tomatoes gained the highest gross margin followed by potatoes and ladyfingers. This result might be due to the fact that farmers used to give much attention to these crops to meet the high demand by Saudi as their food habits go more for these vegetables. On the other hand, the yield of potato crop has declined substantially due to subsidy removal. Likewise, the selling and consumed quantities of potatoes and onion crops in the optimal solution have declined. However, the returns from alfalfa and barley selling have improved significantly, while ladyfingers, eggplant, and zucchini has shown progressive rises in the optimal amount of the balance of the crop.

The returns from the optimal solution substantially exceed the actual situation by approximately four times. Results of the LP model realize that although tomatoes gained the highest gross margin in the ground, they disappear in the optimal solution due to input constraints. The optimal cultivated crop area decreased for potatoes and onion crops but increased for ladyfinger, eggplant, zucchini, barley, and alfalfa. Within the optimal solution, the quantity of seed, water requirements, fertilizers, and energy decrease, and conversely, the amounts of labor and oil increase. Whereas the land was totally used. In conclusion, subsidy removal lead to the reduction of the consumption of the total amount of the important constraints in the regions, energy, seeds, fertilizers, labor, and water.

The results of the optimal model showed that water constraint reaches its peak in the summer season while the labor constraint reaches its highest records during the cultivation and harvesting periods. According to the LP results, farmers in the study area do not use their resources efficiently under the current situation of subsidy removal.

PAM results showed that tomatoes, ladyfinger, eggplant, zucchini, barley, and alfalfa are competitive and received indirect subsidies on an exportable basis. However, potatoes are negatively protected (the private price of the crop output is less than its parity). Moreover, the result confirmed that the government had not protected crop production during the surveyed period. It also revealed that the opportunity for importing all cultivated crops, under the current situation, is more profitable than domestically producing them. In the same line, results also revealed that farmers in the study area need government protection to continue in the business and to compete with imported agricultural products.

Thus, to achieve the maximum benefits of subsidy removal from the energy sector, the agricultural authority should adopt good extension programs to improve farmers' knowledge and skills in the field of optimal farm management practices and efficient use of resources.

Contribution

Raga M Elzaki motivated and planned the study, constructed and performed analysis of the LP and PAM models; interpreted the results, and wrote the first draft paper and literature review. Mutasim M Elrasheed coordinated the study and helped in the discussions, writing, editing and revising the final draft. Nagat A Elmulthum wrote literature review. All the authors revised and proofed the final version of the article.

Declaration of competing interest

The authors declare no conflict of interest.

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